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Small-animal whole-body imaging using a photoacoustic full-ring array system

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ABSTRACT

In this report, we present a novel 3D photoacoustic computed tomography (PACT) system for small-animal whole-body imaging. The PACT system, based on a 512-element full-ring transducer array, received photoacoustic signals primarily from a 2-mm-thick slice. The light was generated by a pulse laser, and can either illuminate from the top or be reshaped to illuminate the sample from the side, using a conical lens and an optical condenser. The PACT system was capable of acquiring an in-plane image in 1.6 s; by scanning the sample in the elevational direction, a 3D tomographic image could be constructed. We tested the system by imaging a cylindrical phantom made of human hairs immersed in a scattering medium. The reconstructed image achieved an in-plane resolution of 0.1 mm and an elevational resolution of 1 mm. After deconvolution in the elevational direction, the 3D image was found to match well with the phantom. The system was also used to image a baby mouse *in situ;* the spinal cord and ribs can be seen easily in the reconstructed image. Our results demonstrate that the PACT system has the potential to be used for fast small-animal whole-body tomographic imaging.

Keywords: Whole-body imaging, photoacoustic tomography, full-ring transducer array, spinal cord.

1. INTRODUCTION

Due to the widespread use of animal models for human diseases, animal imaging plays an important role in biomedical studies. Previously, the majority of small-animal whole-body imaging systems were based on radioactive techniques such as micro-computed tomography (micro-CT) and positron emission tomography (PET). However, the potentially harmful radiation prevents repeated usage of these techniques. The photoacoustic (optoacoustic) technique has recently emerged as an important tool for small-animal imaging [1]. By combining optical sensitivity and ultrasonic imaging depth scalability, this hybrid technology provides high-resolution images beyond the soft depth limit of conventional optical imaging technologies. Over the past few years, several array-based photoacoustic whole-body imaging systems have been proposed, including 64-element arc array [2, 3], 64-element half-ring array [4], and 128-element hemisphere array [5]. However, these systems have either limited spacial resolution or long data acquisition time. In this report, we present a novel whole-body imaging system based on a 512-element full-ring transducer array.

2. SYSTEM DESIGN

Figure 1 shows the schematic diagram of the system. The key components include a 512-element full-ring transducer array, a 64-channel data acquisition (DAQ) system, an optical parametric oscillator (OPO) laser, and a Ti:sapphire laser.

The 512-element full-ring transducer array (Imasonic, Inc.) has a center frequency of 5 MHz and a reception bandwidth greater than 80%. The piezocomposite elements are spaced with a lateral pitch of one wavelength (0.3 mm) and kerf of 0.1 mm. The array element is cylindrically focused to form an imaging slice of about 2 mm thickness. In order to save the number of DAQ channels, 8:1 multiplexing is used. As such, a 512-element capturing requires 8 laser pulses [6].

The excitation source consists of two lasers. An optical parametric oscillator (OPO) laser system (Opotek, Inc.), with tunable wavelength from 400 to 680 and 740 to 2000 nm, and a Ti:sapphire laser (Symphotic TII) tunable from 680 to 900 nm. The combination of two lasers provides a solid coverage from 400 to 2000 nm for studying new optical

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contrasts. The system initially used top illumination for brain imaging [7]. For small-animal whole-body imaging, side illumination is introduced by using a conical lens and a lab-made optical condenser.

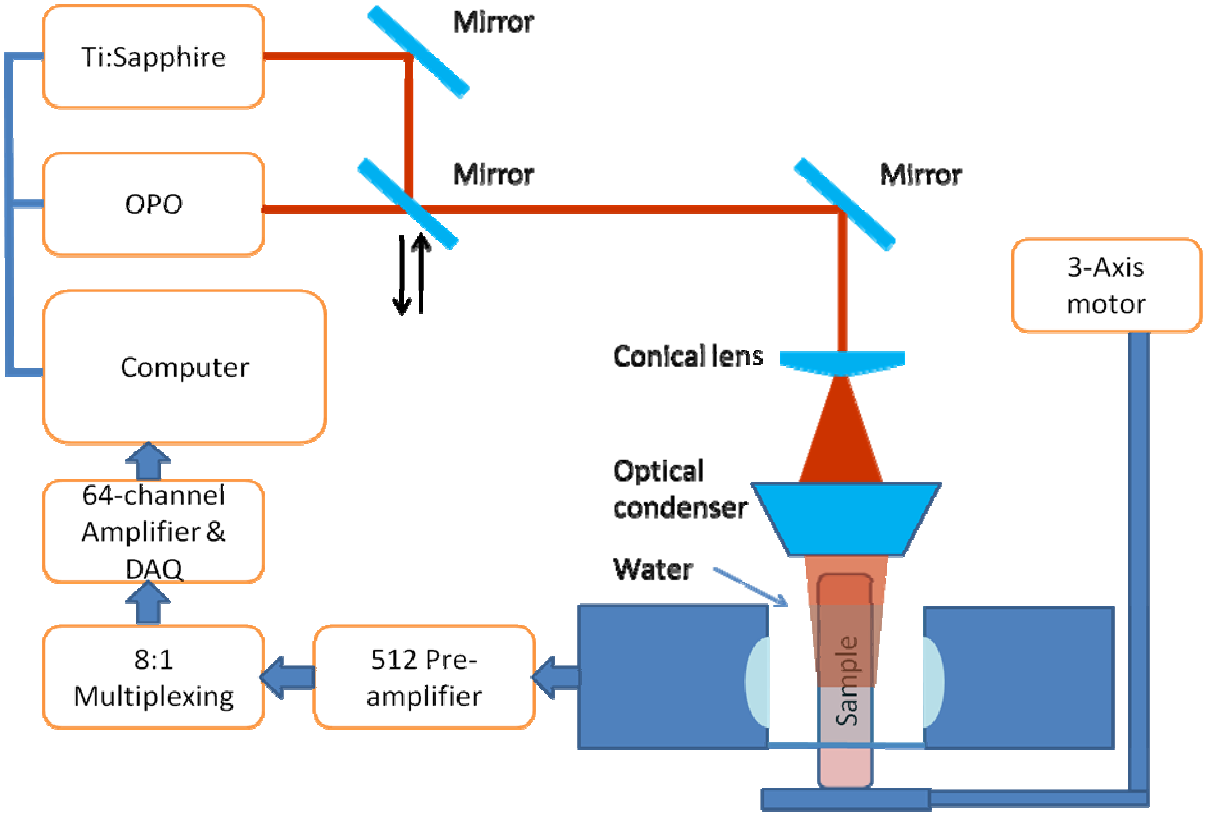

Figure 1. Schematic diagram of the full-ring whole-body scanning system.

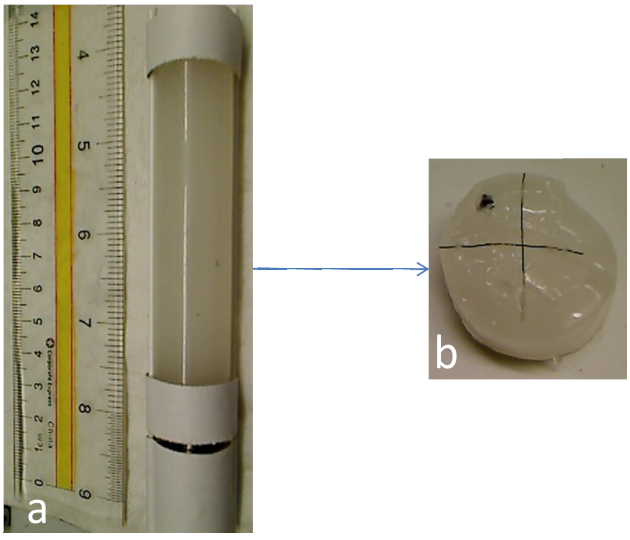

Figure 2. a. The tissue mimic crylindrical phantom made with 1% intralipid solution; b. The graphite and hairs embedded in the phantom.

3. RESULTS

To validate the system performance, we first imaged a cylindrical phantom embedded with two crossing human hairs and a piece of graphite (Figure 2). By scanning the phantom for 8 mm along elevational direction, we obtained a 3D image shown in Figure 3a. Based on the image, we quantified the in-plane resolution to be 0.1 mm and the elevational resolution to be 1 mm. Because our scanning range covers the whole imaging object, and the point distribution function is shift-invariant in elevation direction, we used the Richardson-Lucy deconvolution algorithm to improve the reconstructed image. Figure 3b shows the deconvolved image, where the elevational resolution is improved up to 0.2 mm.

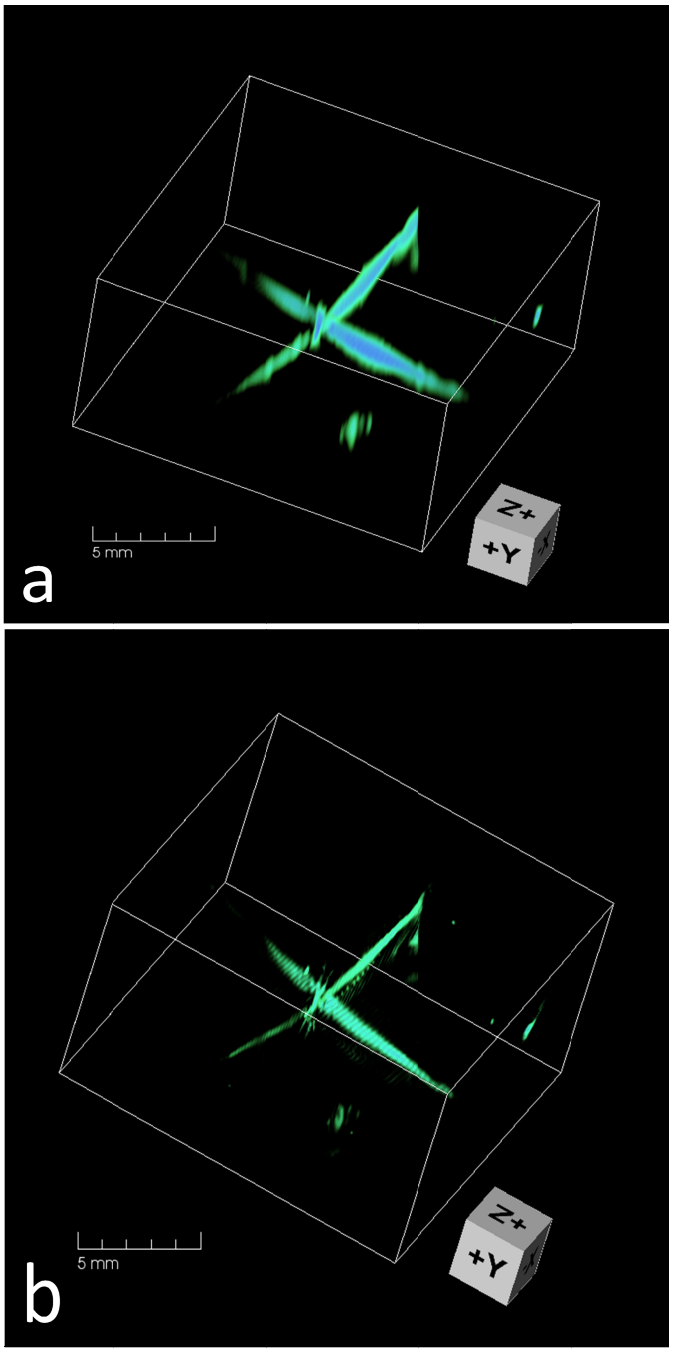

Figure 3. a. Reconstructed 3D photoacoustic image; b. Photoacoustic image after deconvolution in elevational direction.

We also imaged a 1-day-old nude mouse *in situ*. In this experiment, we used the 532 nm wavelength from the OPO laser to illuminate from the top. The optical fluence (10 mJ/cm^2) was under the ANSI safety limit (31 mJ/cm^2). All the imaging procedures were conducted in compliance with the experimental protocols approved by Washington University in St. Louis. Figure 4a shows the maximum-amplitude-projected photoacoustic image, where most of the features can be easily identified.

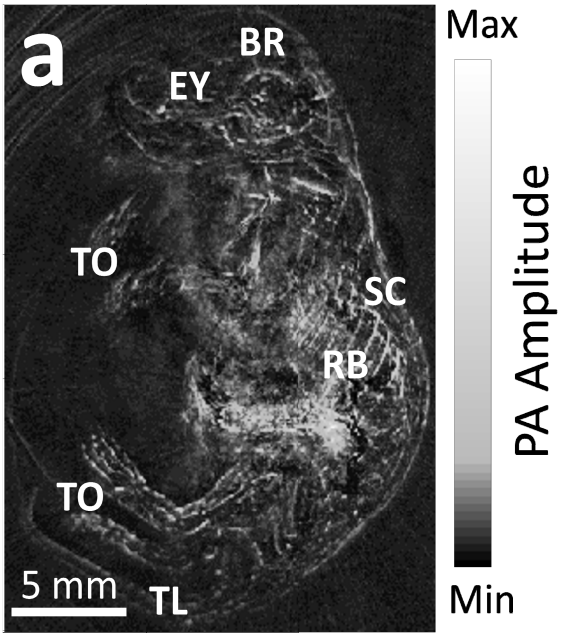

Figure 4. a. Maximum-amplitude-projected photoacoustic image of a 1-day-old nude mouse imaged at 532 nm laser wavelength; b. A photograph of the baby mouse. BR, brain; EY, eye; RB, rib; SC, spinal cord; TO, toes; TL, tail.

4. CONCLUSION

A new small-animal whole-body imaging system has been developed based on the full-ring transducer array. The new system has an in-plane resolution of 0.1 mm and elevational resolution of 1 mm. Using the Lucy-Richardson deconvolution algorithm, the elevational resolution can be further improved to 0.2 mm. We also presented an *in situ* image of a baby mouse, where the spinal cord, ribs and major blood vessels can be seen easily.

5. ACKNOWLEDGEMENTS

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